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RESEARCH AT THE STANFORD CENTER FOR RADAR ASTRONOMY

R search conducted in whole or in part under NASA Grant no. 377 includes theoretical and experimental radio and radar studies of lunar and planetary ionospheres, atmospheres, and surfaces, and radar studies of the sun and interplanetary medium.

PLANETARY RESEARCH

Cislunar Gas Studies

A preliminary note published in the Journal of Geophysical Research for September 1, 1965 (also issued as Sci. Rpt. no. 8 on this contract) described an experimental radar technique for measuring differential group delay to an accuracy of 10 μsec and presented results of five measurements. Since that time, the 25 and 50 Mc radars have been modified to improve power output and time resolution and, during the months of July and August, were used to determine cislunar electron content on 60 consecutive lunar meridian transits.

Ionospheric electron contents, determined by the Faraday rotation method on signals from Syncom III, were subtracted from each radar determination of total content. The results of this experiment reinforce the earlier conclusion that there are two distinct regions beyond the ionosphere. Within the solar wind wake of the earth, in the quadrant opposite the sun, the average cislunar electron density beyond the ionosphere is approximately $175 \pm 50\ \mathrm{cm}^{-3}$. In the general direction of the sun, where most of the radar path is beyond the shock wave boundary, the average density beyond the ionosphere is $50 \pm 50\ \mathrm{cm}^{-3}$. The wake density appears to change on a day-to-day basis while the shape and direction are different from month to month.

Scientific Report no. 12 by Philip Yoh describes and summarizes the simultaneous Doppler and Faraday lunar radar data taken for five consecutive months in early 1964. The data originally suggested that the "chirp" investigation might prove fruitful. It is felt that these two different techniques produce strikingly similar conclusions about the magnetospheric wake density.

In addition to the cislunar content analysis, reduction of the chirp returns from the standpoint of lunar surface characteristics has continued. The transmitted signals consisted of 2-1/2 second long, 100 kHz wide linear sweeps at about 25 and 50 MHz. The reflected signals were mixed with a signal having the same frequency-time variation, which resulted in targets of different ranges showing different frequencies (constant for stationary targets). The heart of the reduction is, therefore, a spectral analysis of the received signals.

This is done most flexibly and conveniently using digital techniques: the recorded signals are first digitally sampled using the IBM 1620 computer and then analyzed with the much faster IBM 7090 at the Stanford Computation Center. The short duration (2.5 sec) of each echo limits the frequency (range) resolution to about 2.5 Hz since the maximum lag in the autocorrelation should be a small fraction of the duration of the record. The compromise between a long lag (narrower spectral window) and a long record (a good estimate of the autocorrelation) was made with a maximum lag of about one second. This fixes the spacing of adjacent estimates of the power spectral density to 2 Hz.

Both the change in range and the range-rate (Doppler) of the moon cause the frequency corresponding to a particular range interval on the moon to change. This change is insignificant compared to the window during one return. But in order to average many minutes worth of returns together, it is necessary to remove (reverse) the change. Fortunately, this is easily done since it is very closely parabolic in shape during the periods near transit when the records are made.

While the spectra of the individual 2.5 sec records are considerably different from each other, even when they are adjacent and show several peaks, a relatively smooth curve can be obtained by superimposing many of them. Because the signal-to-noise ratio isn't sufficiently high, only the first 400 to 600 μsec of the 11,600 μsec total delay from the front to the limb can be seen in these composites. However, it is in this region that the echo changes most rapidly with range and the high resolution obtainable using these techniques is most useful.

Besides computing the average for each range interval over many 2.5 sec records, the variance and correlation coefficients with neighboring range intervals were also obtained. The ratio of the RMS fluctuation about the mean to the mean for each range increased from about 0.4 for range intervals not including the moon to 0.6 - 0.7 for those near the peak of echo strength on 50 MHz and from about 0.2 to 0.4 - 0.8 on 25 MHz. The plots of σ/mean vs. range and variance vs. range are very similar to those of mean vs. range.

The nature of the reflection of this kind of signal is not yet well understood but is felt to be similar in some aspects to that of short pulses. A preliminary cross section of the moon calculated from these records is several orders of magnitude smaller than those measured elsewhere.

Planetary Surface Mapping

Work is continuing on bistatic-radar methods for the study and mapping of planetary surfaces. Thus far we have shown that it is possible to reconstruct the radar brightness distribution of a planetary surface from the interference pattern formed by the direct, and reflected, rays when the surface is illuminated with radio frequencies from the earth. Previous reports describe these techniques in detail.

Experimental verification of the predicted response function has been obtained by optical simulation and further studies in this vein are continuing.

A theoretical investigation of the effects of various surface parameters has been started but so far this subject is not well understood. This is concomitant with the design of optimum filters for mapping application.

Planetary Atmospheres and Ionospheres

The Stanford study of the Mariner IV occultation data has in part been funded through NsG-377. The results of this work are presented in a Scientific Report, issued jointly by NsG-377 (Sci. Rpt. no. 15) and NASA contract NGR-05-020-065 (Sci. Rpt. no. 2).

In addition, a study of the problems related to conducting a radio occultation experiment on the Mariner mission to Venus was started during this reporting period. While the Martian atmosphere was so tenuous that it required high precision measurements to detect its effects on radio signals, the Cytherean atmosphere may actually be so dense that no radio signal can penetrate along a path tangential to the surface of Venus. These and other problems are subject to further studies in order to optomize the radio occultation experiments scheduled for 1967.

Digital Radio Polarimeter Observations of Jovian and Solar Decametric Emissions

Since August 1965 a digital radio polarimeter has been used at the Center to observe radio noise bursts at 22.2 Mc from Jupiter and from the sun. A pair of cross-polarized antennas feed a pair of receivers with common local oscillators, which translate the radio signals with coherent phase down to 550 cps. These signals, recorded on FM magnetic tape, are later played back through two identical band-pass filters and digitized at a sampling rate of 1.65 kc/sec per channel. The digitized data are then fed to an IBM 7090 computer, which calculates and plots the complete Stokes polarization parameters with a time resolution of one second.

Analysis of Jovian emission at 22.2 Mc confirms the predominance of right-hand polarization reported by others, but also shows a difference in axial ratio for emissions from the different sources. The axial ratio is seen to vary smoothly with time during a storm independently of noise power, and orientation of the polarization ellipse shows no appreciable Faraday rotation other than that from the earth's ionosphere.

Analysis of Type III solar bursts shows no change of either axial ratio or orientation of the ellipse (other than earth-Faraday) from burst to burst in a given storm. However, the percentage of polarization varies within each burst and also during a group of bursts, being highest in the initial burst and decreasing by at least 5 percent in the final burst.

SPACECRAFT TECHNIQUES

Signal Channel Coding Schemes

In 1965 a coding scheme for additive noise channels with feedback was developed by Schalkwijk for this contract. His results were published as Sci. Rpt. no. 10 (see list of reports). This coding scheme, under the condition of noiseless feedback, achieves channel capacity for both the band limited and band unlimited channels. Almost immediately, the question of realizability and practical utility arises. During this reporting period, this question has been studied.

Basically the scheme is one of analog coding under an average power constraint P_{av}. A code book of M messages is uniformly spread over the interval $(0, 1)$ on the real line. To send message m_i, the transmitter sends an amplitude proportional to the position in $(0, 1)$ of m_i. The receiver calculates its maximum likelihood estimate of m_i and sends it back to the transmitter. The transmitter then transmits correction data to the receiver, which then sends back a new estimate of the message m_i. This iterative process is continued N times for each message transmitted. N is determined by the required probability of error P_e for the operating rate of transmission R, bandwidth W, and signal-to-noise ratio S/N.

Being of particular interest, the bandlimited channel was studied. As originally derived, the coding scheme achieved channel capacity C in the limit, i.e., with an unlimited number of messages M and iterations N. To be practical, N must be small, e.g., 10 or 20 at most. It was found that favorable situations do exist. A series of graphs has been constructed to show the possible modes of operation and the resultant P_e and N for specified system parameters M, S/N_o and relative transmission rate R/C. For $M \leq 1000$ and $S/N_o \geq 0$ db, it is possible to achieve error probabilities $P_e \leq 10^{-6}$ and relative rates $R/C \gtrsim 0.5$ with $N \leq 20$. Operation for $S/N_o < 0$ db is possible under increased N.

The important conclusion of the study was that, theoretically, the coding scheme can operate under a sizable code book and a few iterations and still achieve low probability of error and high transmission rate. It remains to realize the system; work will continue in this area. The two most difficult problems will be minimization of the system performance degradation under non-ideal signal waveforms and receiver equipment and the accommodation of loop delay.

Plasma Effects on Space Probe Tracking

It has been proposed that diurnal variations in the ionosphere cause significant errors in the tracking of space probes such as Mariner IV. To test this hypothesis a computer program using changing ionospheric conditions and space probe positions as parameters has been written. This program plots graphs of expected electron content and Doppler shift vs. time. The typical ionospheric Doppler shift of Mariner IV's telemetry signal (two-way lock) (2.3 kMc) is $\pm$ 0.004 cps maximum or 0.001 cps averaged over the day. This corresponds to an average velocity error component along the ray path of 9×10^{-5} meters/sec. These data are also being analyzed from the standpoint of orbit prediction and trajectory determination.

It was discovered while plotting one-second Doppler frequency residuals from Mariner IV that the primary source of short-term error is caused by the receiving system's counting only zero crossings of the received signal. Methods of digital filtering and smoothing to minimize this error were investigated.

It is hoped that by autocorrelating the one-second Doppler data from Mariner IV, electron streams and bunching can be detected and ranged. An autocorrelation program has been written and debugged. Initial trial runs were hampered by the zero crossing noise mentioned above. Improved Mariner IV data from the Jet Propulsion Laboratory is now being awaited. An additional opportunity for autocorrelation studies may occur when the signal ray path passes near the sun in March.

Receiver Construction Techniques

A comparison and compilation of the advantages and limitations of eight microminiaturization fabrication processes has been completed. Consideration was given to custom linear circuit design as well as design with available linear microcircuits, and included the following topics: frequency capability, range of passive elements, cost, ease of design, reliability, radiation immunity, power capability, and size and weight. This 52-page summary was obtained from a search of the literature published during the period 1963 through 1965, from lectures attended at both Stanford University and the 1965 Wescon Show, and from personal interviews with several representatives of the microcircuits industry.

An effort was made to select objectively the optimum microminiaturization technique for a specifically defined application by means of evaluation charts. During the summer this took the form of a commercial product microminiaturization feasibility study at Granger Associates, Palo Alto.

The steps included:

1. The above-mentioned compilation of qualitative and quantitative statements from current literature to permit the selection of meaningful and representative numbers for the evaluation chart.

2. The selection of representative circuits from a given linear system designed with discrete components.

3. A thorough cost analysis

   a. A market survey of presently available linear microcircuits

   b. Letters sent to 11 companies requesting budgetary quotes for a custom design of the representative circuits chosen in (1).

Numerical priorities were then used to weight the relevant differences between microcircuit alternatives. (Once an alternative is selected using this technique, a significant change in one of the differences, or a change of priority, will permit re-evaluation based completely upon the decision criteria originally followed.)

At the close of the summer a study was initiated at Stanford to provide experience with digital microcircuit design techniques. Digital correlation methods were investigated for determining the range at which a 28-bit bi-phase-modulated code is reflected from meteoritic ionization trails. The investigation included two techniques for code transmission, and five alternative methods for correlation of the returned signal. An approach was selected and system design is presently being implemented.

PUBLICATIONS

Spira, P. M., Digital Measurement of Differential Time Delay of Pseudo Random Coded Signals, Sci. Rpt. no. 6, NsG-377, SU-SEL-65-027, Stanford Electronics Laboratories, Stanford, California, January 1966.

Gee, S., Bistatic-Radar Measurements of Interplanetary Collisionless Shock Waves, Sci. Rpt. no. 9, NsG-377, Tech. Rpt. no. 3606-1, Nonr-225(83), SU-SEL-65-074, Stanford Electronics Laboratories, Stanford, California, October 1965.

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Yoh, P., Radar Studies of the Cislunar Medium, Sci. Rpt. no. 12, NsG-377, SU-SEL-65-091, Stanford Electronics Laboratories, Stanford, California, December 1965.

Tyler, G. L., The Bistatic Continuous-Wave Radar Method for the Study of Planetary Surfaces, Sci. Rpt. no. 13, NsG-377, SU-SEL-65-096, Stanford Electronics Laboratories, Stanford, California, October 1965.

Yoh, P., Lunar Radar Measurements of the Diurnal Exchange of Ionization between the Ionosphere and the Magnetosphere, Sci. Rpt. no. 14, NsG-377, SU-SEL-65-103, Stanford Electronics Laboratories, Stanford, California, December 1965.

Howard, H. T., V. R. Eshleman, G. H. Barry, and R. B. Fenwick, Radar measurements of the total cislunar electron content, J. Geophys. Res., 70, 4357-4363, 1965.

Kliore, A., D. L. Cain, G. S. Levy, V. R. Eshleman, G. Fjeldbo, and F. D. Drake, Occultation experiment: results of the first direct measurement of Mars's atmosphere and ionosphere, Science, 149, 1243-1248, 1965.

Yoh, P., H. T. Howard, B. B. Lusignan, and V. R. Eshleman, Lunar radar measurements of the earth's magnetospheric wake, J. Geophys. Res., 71, 189-194, 1966.

PAPERS PRESENTED

The results of the Mariner IV occultation experiment were presented at the following meetings:

Fifth National Western Meeting, American Geophysical Union, Dallas, Texas 1-3 September 65.

Lunar and Planetary Symposium, Jet Propulsion Laboratory, Pasadena, California 13-18 September 1965.

Ionospheric Research Council, AGARD, NATO, Rome, Italy, 21-25 September 1965.

Fall URSI meeting, Dartmouth College, Hanover, New Hampshire, 19-22 October 1965.

Exobiology Study, National Academy of Sciences, held at Stanford University, Stanford, California 24-25 October 1965.

Space Physics Symposium, Lockheed Missile and Space Company, Palo Alto, California 1 November 1965.

Space Science Symposium, University of California, Berkeley, California 24 November 1965.

Results of radar measurements of the cislunar electron content were presented by Mr. H. T. Howard at the Second Symposium on Radio Astronomical and Satellite Studies of the Atmosphere, Boston, Massachusetts, 19-21 October 1965.